Processing separately the in-wake and off-wake boundary layers: effect on surface fluxes and low cloud cover in the LMDZ GCM

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Introduction

In the LMDZ GCM, moist convection is represented by a set of three parametrizations, namely the thermal scheme (representing boundary layer thermals), the wake scheme (representing density currents) and the Emanuel scheme (representing deep convection); the first two parametrizations are coupled with the convective scheme through two variables, the ALE (Available Lifting Energy, used in the convective trigger) and the ALP (Available Lifting Power, used in the convective closure). This set of parametrizations coupled through the ALE/ALP system made it possible to improve largely the simulation of the diurnal cycle of convection over land and of its variability over ocean (Rio et al., 2009, Rio et al., 2012).

Up to now the boundary layer EDMF scheme is called for the average temperature and humidity profiles, which leads to various deficiencies:

- Technical problem: the off-wake atmosphere is often absolutely unstable.
- The interaction of cold pools with surface fluxes is not represented.
- The Thermal scheme is strongly inhibited as soon as wakes appear, which is incompatible with observations and leads to a lack of low level clouds.

We expect that splitting the boundary layer between the wake and the off-wake regions will bring more reasonable profiles and improve the low level cloud cover.

Surface-Atmosphere coupling

(Equations for heat ; similar equations hold for moisture)

The wakes are supposed to move rapidly above the various sub-surfaces so that surface temperature is homogeneous over each subsurface.

Interface variables for the atmosphere :

- ϕ_i^w , surface heat flux between sub-surface (i) and wake atmospheric column.
- ϕ_i^x , surface heat flux between sub-surface (i) and off-wake atmospheric column.

Interface variables for sub-surface (i) **:**

- T_i^a at begining of time-step, a temperature such that the surface flux ϕ_i is related to the surface temperature $T_{s,i}$ by $\phi_i = K_i C_p (T_i^a - T_{s,i})$.
- K_i : exchange coefficient at the surface.
- Coefficients A_i and B_i such that the linear relationship between T_i^a and ϕ_i implied by the atmospheric column reads $T_i^a = (1/C_p)(A_i + B_i \phi_i \Delta t)$.

Surface-Atmosphere coupling 2

Model equations

In each column (w,i) and (x,i), the atmospheric model yields a linear relation between temperature T_1 at first level and surface flux ϕ :

$$\left\{\begin{array}{lcl} T_{1,i}^{w} & = & \dfrac{1}{C_p}\,(A_i^w \;+\; B_i^w \phi_i^w \Delta t) \\ T_{1,i}^{x} & = & \dfrac{1}{C_p}\,(A_i^x \;+\; B_i^x \phi_i^x \Delta t) \end{array}\right. \tag{1}$$

At each interface (w,i) and (x,i), surface exchange laws yield :

$$\left\{\begin{array}{lcl} \phi_i^w & = & K_i^w (T_{1,i}^w \;-\; T_{s,i}) \\ \phi_i^x & = & K_i^x (T_{1,i}^x \;-\; T_{s,i}) \end{array}\right. \tag{2}$$

Coupling with sub-surface :

$$\left\{\begin{array}{lcl} \phi_i & = & \sigma_w \phi_i^w \;+\; (1-\sigma_w)\phi_i^x \;=\; \phi_i^x \;+\; \sigma_w \delta\phi_i \\ T_i^a & = & \dfrac{1}{C_p}(A_i \;+\; B_i \phi_i \Delta t) \\ \phi_i & = & K_i C_p\,(T_i^a - T_{s,i}) \end{array}\right. \tag{3}$$

(for any variable y : $\delta y \;=\; y^w \;-\; y^x$)

Surface-Atmosphere coupling 3

Solving

From atmosphere to sub-surfaces :

$$\left\{\begin{array}{lcl} K_i & = & K_i^x \; + \; \sigma^w \, \delta K_i \\ T_i^a & = & T_{1,i}^x \; + \; \sigma^w \dfrac{K_i^w \; \delta T_{1,i}}{K_i} \end{array}\right. \tag{4}$$

$$\left\{\begin{array}{lcl} K_i^{'w} & = & \dfrac{K_i^w}{1 \; - \; B_i^w K_i^w \Delta t} \\ \\ K_i^{'x} & = & \dfrac{K_i^x}{1 \; - \; B_i^x K_i^x \Delta t} \end{array}\right. \tag{5}$$

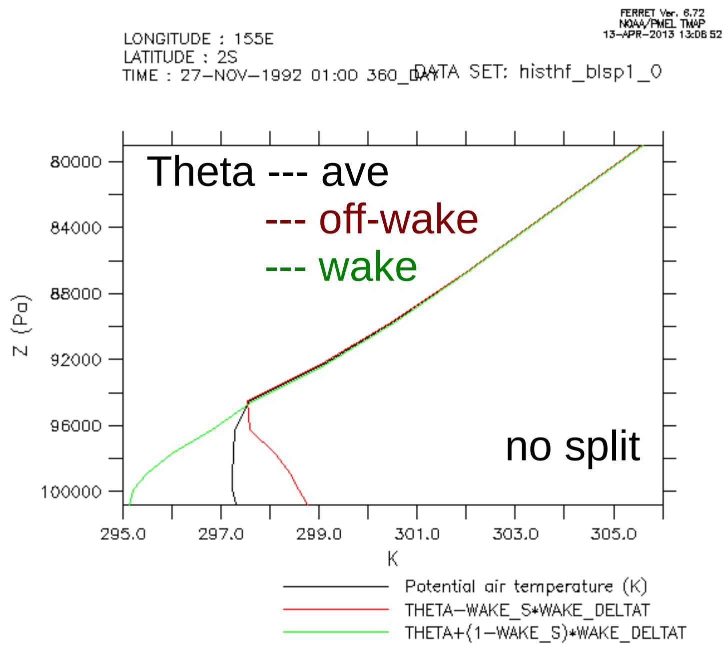
$$\left\{\begin{array}{lcl} K_i' & = & K_i^{'x} \; + \; \sigma^w \, \delta K_i' \\ A_i & = & A_i^x \; + \; \sigma^w \dfrac{K_i^{'w} \; \delta A_i^w}{K_i'} \end{array}\right. \tag{6}$$

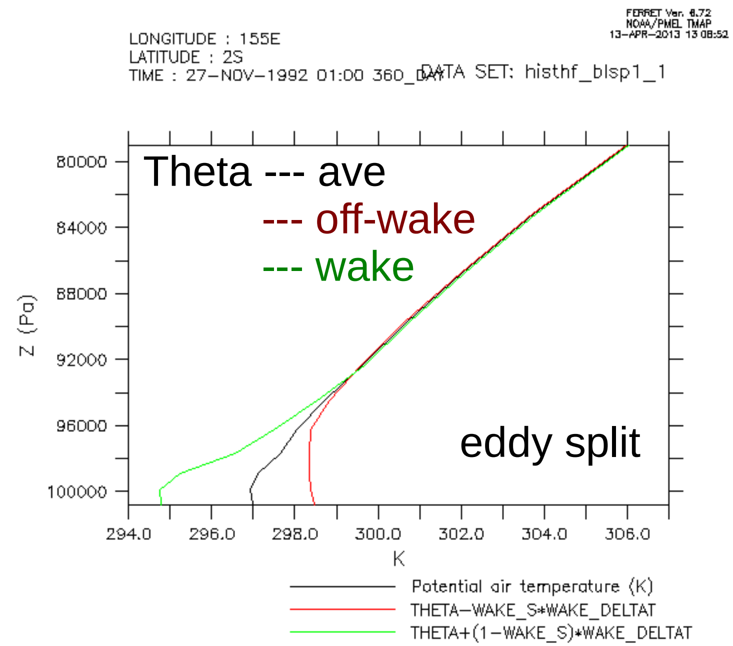
$$B_i \; = \; B_i^x \; + \; \sigma^w B_i^x \frac{\delta K_i}{K_i}(1 \; + \; \frac{K_i^{'w}}{K_i'}) \; + \; \sigma^w \frac{K_i^{'w} K_i'}{K_i' K_i} \delta B_i \tag{7}$$

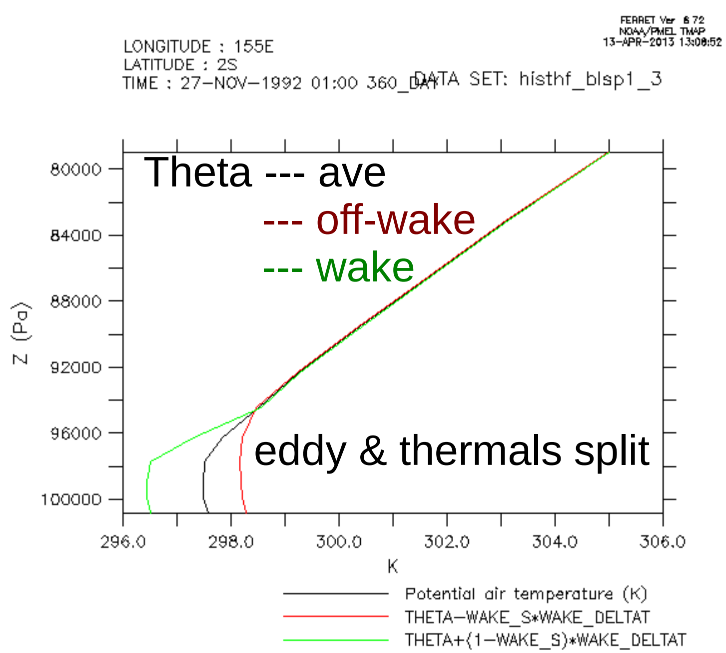
From sub-surfaces to atmosphere :

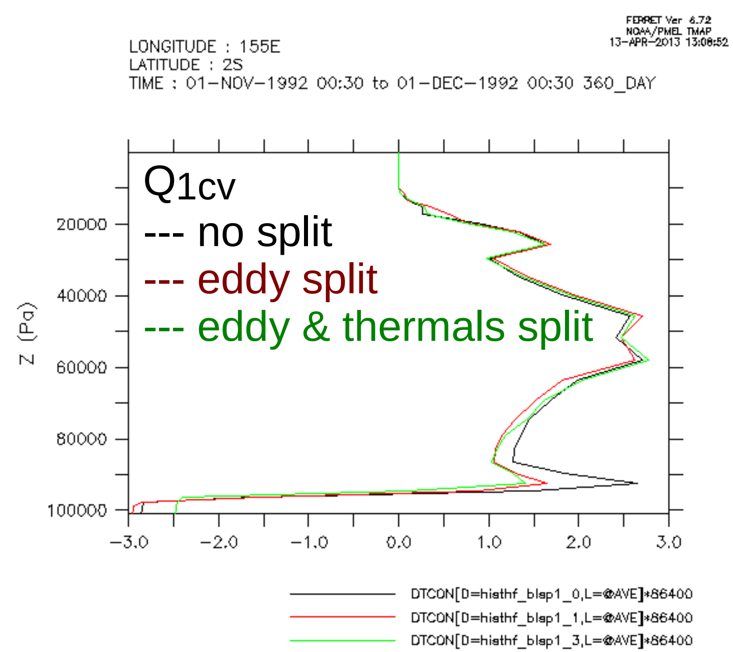
$$\left\{\begin{array}{lcl} \delta\phi_i & = & \dfrac{K_i^{'w} K_i^{'x} \delta A_i \; + \; \phi_i \delta K_i'}{K_i'} \\ \phi_i^w & = & \phi_i \; + \; (1 - \sigma^w) \delta\phi_i \\ \phi_i^x & = & \phi_i \; - \; \sigma^w \delta\phi_i \end{array}\right. \tag{8}$$

3 -TOGA-COARE 1D simulations

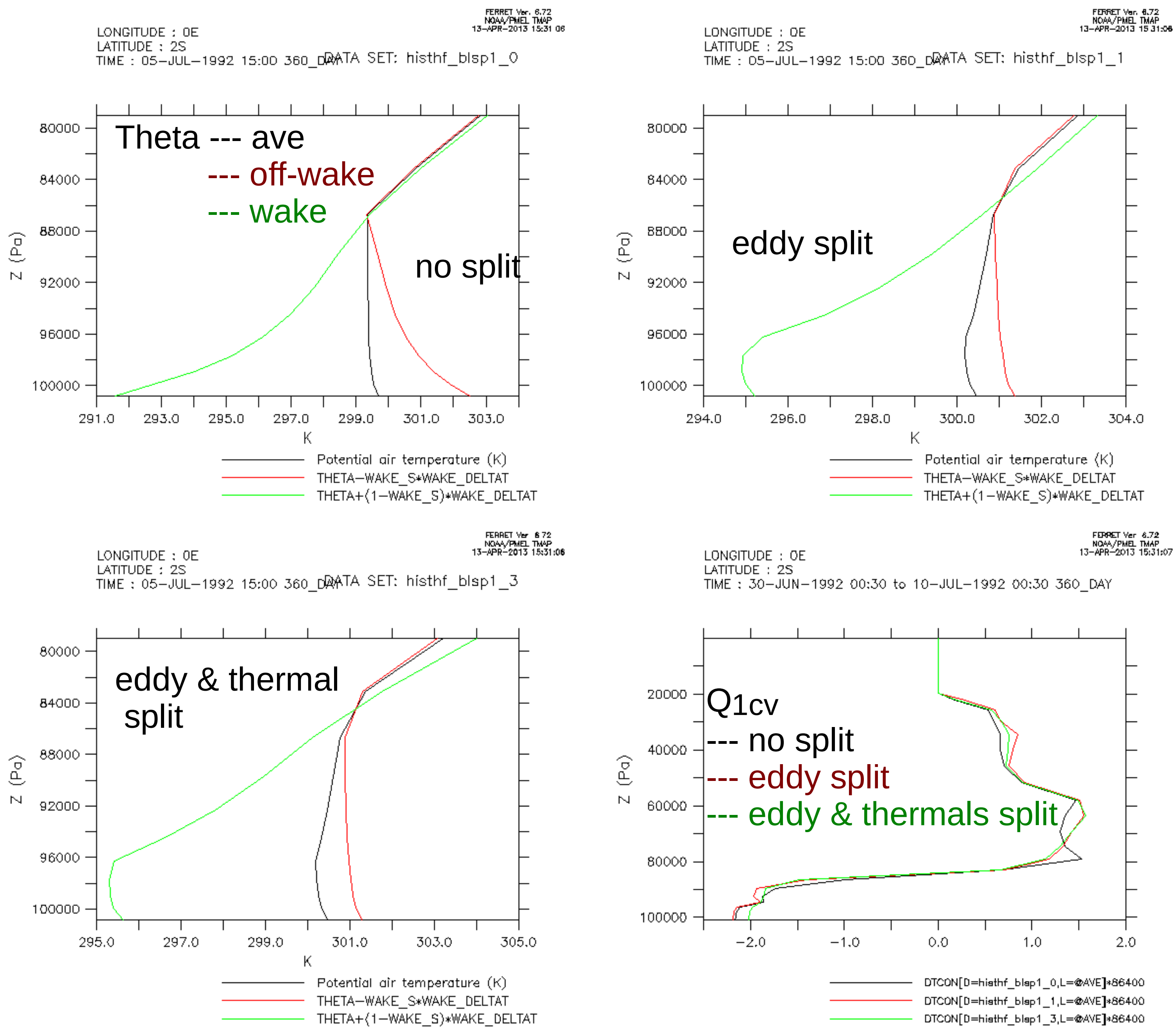








4 – Radiative-Convective Equilibrium 1D simulations (Semi-arid conditions)



5 -TWPICE 1D simulations